

-22-

Claims

1. A broad-band deep-ultraviolet achromatic catadioptric imaging system, comprising:

a focusing lens group including a plurality of lens elements, all formed from a single refractive material type, with refractive surfaces thereof disposed at first predetermined positions along an optical path of the system and having curvatures and said positions selected to focus ultraviolet light at an intermediate image within the system, and simultaneously to also provide in combination with the rest of the system, high levels of correction of both image aberrations and chromatic variation of aberrations over a wavelength band including at least 0.20-0.29 μm ,

a field lens group with a net positive power disposed along said optical path proximate to said intermediate image, the field lens group including a plurality of lens elements formed from at least two different refractive materials with different dispersions, with refractive surfaces of the lens elements of the field lens group disposed at second predetermined positions and having curvatures selected to provide correction of chromatic aberrations including at least secondary lateral color of the system over said wavelength band,

a catadioptric group including a first optical element having at least a concave reflective surface with a central optical aperture therein disposed along said optical path proximate to said intermediate image so that ultraviolet light from the intermediate image can pass therethrough, the catadioptric group also including a second optical element which is a lens with a reflective mirror coating on a rear surface of said lens except for a central area on said rear surface where said mirror coating is absent, the optical elements of said catadioptric group being arranged such that ultraviolet light from the intermediate image transmitted through said central optical aperture of said first optical

-23-

element of said catadioptric group passes through the lens portion of said second optical element of said catadioptric group, reflects from said reflective mirror coating on said lens rear surface, passes back through said lens portion towards said concave reflective surface of said first optical element, is reflected thereby and passes a third time through said lens portion of said second optical element and through said central area of said lens rear surface to form a final image beyond said catadioptric group.

2. The imaging system of claim 1 wherein said wavelength band includes 0.20-0.40 μm .

3. The imaging system of claim 1 wherein said wavelength band includes 0.193 μm .

4. The imaging system of claim 1 wherein said single refractive material type of said focusing lens group is fused silica.

5. The imaging system of claim 1 wherein said field lens group is formed from lens elements made of fused silica and a fluoride glass.

6. The imaging system of claim 1 wherein said first optical element of said catadioptric group comprises a concave mirror with a central hole therein forming said central optical aperture.

-24-

7. The imaging system of claim 1 wherein said first optical element of said catadioptric group comprises a meniscus lens with a concave reflective surface coating thereon.

8. The imaging system of claim 7 wherein said central optical aperture is formed by a central hole in said meniscus lens.

9. The imaging system of claim 7 wherein said central optical aperture is formed by a central area on said meniscus lens where said concave reflective surface coating is absent.

10. The imaging system of claim 1 wherein said catadioptric group is characterized by reflective surface curvatures selected to provide at least a 0.8 numerical aperture and a 0.5 mm field of view for said final image of the imaging system.

11. A catadioptric imaging system, comprising:
a first negative lens,
a second positive biconvex lens closely spaced to the first lens to form a substantially zero-power corrector group for chromatic variations of image aberrations,
a third negative meniscus lens spaced from the second lens,
a fourth negative meniscus lens with concave surfaces of the third and fourth lenses facing each other,
a fifth positive biconvex lens,
a sixth positive meniscus lens,

-25-

a seventh meniscus lens of near zero-power with concave surfaces of the sixth and seventh lenses facing each other, the third through seventh lenses being closely spaced together to form a focusing lens group with minimal image aberrations, said focusing lens group providing an intermediate image,

eighth, ninth and tenth lenses forming an achromatic field lens group positioned proximate to said intermediate image, said field lens group including at least one positive convex lens of a different refractive material type than all other lenses in the system and at least one negative meniscus lens, the field lens group having a net positive power,

an eleventh negative meniscus lens with a convex surface facing said first lens having a reflective coating thereon and with a first central optical aperture therein proximate to said intermediate image, and

a twelfth near zero-power, substantially flat lens with a reflective coating on a surface facing away from the first lens with a second central optical aperture therein, said twelfth lens spaced apart from the eleventh lens, the eleventh and twelfth lenses with their respective reflective coatings forming a catadioptric group providing a light focusing relay for the intermediate image to provide a final image proximate to the second optical aperture.

12. The imaging system of claim 11 wherein the third lens is spaced at least 30 mm from the second lens, and said twelfth lens is spaced at least 30 mm from the eleventh lens.

13. The imaging system of claim 11 wherein the focusing lens group, field lens group and catadioptric group have refractive and reflective surfaces that are characterized by the following dimensional values:

-26-

Surface #	Radius of Curvature (mm)	Spacing (mm)	Material
1	1105.7	4.000	fused silica
2	53.051	2.500	air
3	284.061	5.000	fused silica
4	- 57.181	60.000	air
5	39.782	15.000	fused silica
6	13.379	7.977	air
7	- 12.955	5.169	fused silica
8	- 17.192	1.000	air
9	42.964	8.000	fused silica
10	- 55.269	1.000	air
11	18.436	8.000	fused silica
12	91.574	6.253	air
13	- 20.802	4.000	fused silica
14	- 21.768	17.120	air
15	7.217	5.494	fused silica
16	2.259	3.000	CaF ₂ glass
17	- 11.760	1.500	fused silica
18	373.721	39.730	air
19	flat	7.000	fused silica
20	flat	- 7.000	reflector/ fused silica
21	flat	- 36.000	air
22	50.470	- 9.500	fused silica
23	64.290	9.500	reflector/ fused silica
24	50.470	36.000	air
25	flat	7.000	fused silica
26	flat	1.500	air

-27-

14. The imaging system of claim 11 wherein the focusing lens group, field lens group and catadioptric group have refractive and reflective surfaces that are characterized by the following dimensional values:

Surface #	Radius of Curvature (mm)	Spacing (mm)	Material
1	- 67.007	4.000	fused silica
2	50.308	2.000	air
3	120.297	6.000	fused silica
4	- 37.494	30.636	air
5	24.138	10.000	fused silica
6	13.441	9.532	air
7	- 13.518	7.546	fused silica
8	- 17.997	1.000	air
9	34.465	6.000	fused silica
10	- 517.022	1.000	air
11	18.268	10.000	fused silica
12	965.352	4.181	air
13	- 30.177	9.746	fused silica
14	- 28.138	7.892	air
15	- 19.346	2.500	fused silica
16	- 36.530	1.000	air
17	6.687	5.026	fused silica
18	2.044	0.017	air
19	2.044	2.000	CaF ₂ glass
20	- 90.635	36.108	air
21	- 908.968	7.000	fused silica
22	- 1000.0	- 7.000	reflector/ fused silica
23	- 908.968	- 36.000	air
24	48.244	- 9.500	fused silica

-28-

			reflector/ fused silica
25	63.204	9.500	
26	48.244	36.000	air
27	- 908.968	7.000	fused silica
28	- 1000.0	1.500	air

15. A method of inspecting objects for defects comprising:

illuminating an object with ultraviolet radiation having a wavelength which is less than 400 nanometers;

forming a plurality of fluorescent ultraviolet images with a single broadband collector of ultraviolet radiation, each image detected at a wavelength band separated from other wavelength bands of images of the same object by at least 50 nanometers;

converting said plurality of images to visible light for visual inspection of defects.

16. A method of inspecting objects for defects comprising:

illuminating an object with ultraviolet radiation at multiple wavelengths,

forming a multi-wavelength ultraviolet image with a single broadband collector of ultraviolet radiation, and

detecting said multi-wavelength ultraviolet image.

17. The method of claim 16 wherein said object being inspected comprises a wafer surface including photoresist.

-29-

18. The method of claim 16 wherein said object being inspected comprises a phase-shift photomask.

19. The method of claim 16 further comprising analyzing said multi-wavelength ultraviolet image so as to identify and classify defects on said object.

20. A method of inspecting objects for defects comprising:

illuminating an object with ultraviolet radiation at multiple wavelengths separated by at least 10 nm,

for each ultraviolet illumination wavelength, forming a corresponding ultraviolet image slice of the object at a different focal plane from image slices corresponding to the other illumination wavelengths, and

forming a composite image by means of computer integration of the image slices, the composite image characterized by a greater depth of focus than any of its constituent image slices.